Iterative ΔB_0 and T_2^* Correction for Radial Multi-Gradient-Echo Imaging

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Abstract

An iterative correction of off-resonance and relaxation artifacts based on ΔB_0 and R_2* maps is investigated regarding its ability to improve image quality in radial multi-gradient-echo imaging. In contrast to previously proposed direct approaches, it is shown to achieve an almost complete suppression of these artifacts in simulations. Moreover, the image quality is demonstrated to primarily depend on the resolution of the maps. The availability of additional information on the spatial distribution of ΔB_0 and T_2*, for instance from a separate reference scan, therefore appears essential to permit the use of longer echo trains in radial multi-gradient echo imaging.

Introduction

Radial multi-gradient-echo acquisitions [1,2] are particularly sensitive to off-resonance and relaxation effects, since they sample the central *k*-space area at very different points in time after the excitation. Any inconsistencies in the amplitude or phase of these samples lead to severe image artifacts. Applying a conjugate phase reconstruction to correct the phase errors caused by off-resonance improves image quality considerably [3]. Incorporating into it a compensation for the relaxation-induced amplitude errors enhances results further [4]. For echo train lengths of more than five, however, these direct approaches to a ΔB_0 and T_2* correction have basically failed to yield a satisfactory image quality in practice so far.

Theory

An appropriate model for the acquired data $\underline{m}$ is given by

$$\underline{m} = E\underline{x}, \qquad \text{with } E_{\kappa\rho} = e^{-R_2^*(r_\rho)t(k_\kappa)} e^{i\Delta\omega(r_\rho)t(k_\kappa)} e^{i r_\rho k_\kappa}.$$

The direct approaches approximate the unknown image $\underline{x}$ by

$$\underline{x} \approx E'D\underline{m}, \qquad \text{with } E'_{\rho\kappa} = e^{R_2^*(r_\rho)t(k_\kappa)} e^{-i\Delta\omega(r_\rho)t(k_\kappa)} e^{-i r_\rho k_\kappa}.$$

The first exponential is only included if a T_2* correction is attempted. The optional diagonal matrix D serves the compensation for variations in the sampling density.

The iterative approaches solve the typically large linear system of equations

$$E^H E\underline{x} = E^H \underline{m},$$

for instance with the conjugate gradient method.

Methods

The data set shown in Fig. 1 was used to simulate radial multi-gradient-echo acquisitions with different echo train lengths. The ΔB_0 and R_2* maps were derived from several radial single-gradient-echo acquisitions with different echo times.

For both the direct and the iterative approaches a segmentation of time was employed. In the first case, the number of segments was set equal to the number of echoes. In the second case, the interpolation proposed in Ref. 5 and a fixed number of ten segments was selected.

Results

In Fig. 2, results obtained for an echo train length of nine are summarized. The iterative ΔB_0 and T_2* correction efficiently eliminates all artifacts, including the streaking remaining present with the comparable direct approach. Some artifacts reappear, however, if the spatial resolution of the ΔB_0 and R_2* maps is reduced ninefold.

Qualitatively similar observations were made for other echo train lengths.

Discussion and Conclusion

The phantom images demonstrate the principal feasibility of iteratively reconstructing images free of off-resonance and relaxation artifacts from radial multi-gradient-echo acquisitions with longer echo trains. At the same time, a derivation of the ΔB_0 and R_2* maps from the imaging data entails a decrease in the spatial resolution of these maps with increasing echo train length and thus prevents a complete artifact suppression. While a good compromise between fidelity and resolution still has to be found for the maps, an alternative, probably more promising strategy appears to be the separate acquisition of additional information on the spatial distribution of ΔB_0 and T_2* for the correction, for instance in form of a reference scan.

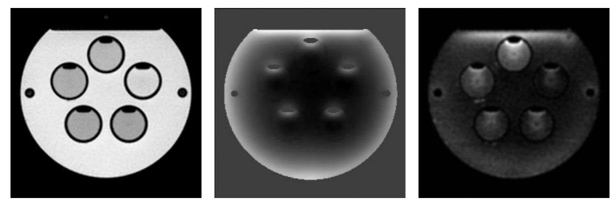

Fig. 1. Data set used in the simulations. Shown are (from left to right) one of the measured images, and the ΔB_0 and R_2 maps derived from them.*

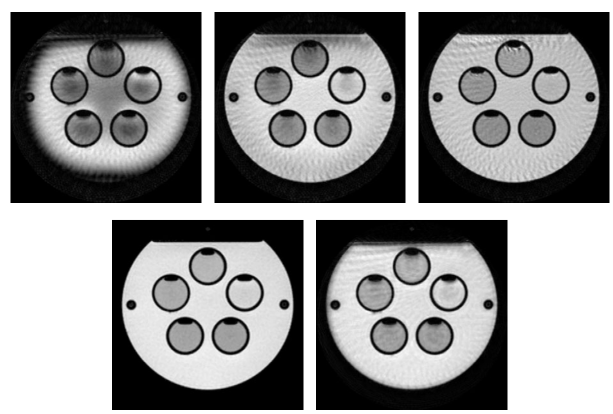

Fig. 2. Results of different reconstructions using (top, from left to right) the direct approach without, with ΔB_0, and with ΔB_0 and T_2 correction, and (bottom) the iterative approach with ΔB_0 and T_2* correction. For the last image, the spatial resolution of the ΔB_0 and R_2* maps was reduced.*

References

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